

532 Rec'd PCT/PTO 13 SEP 2000

FORM PTO-1390  
U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY DOCKET NUMBER  
THOM-0012

TRANSMITTAL LETTER TO THE UNITED STATES  
DESIGNATED/ELECTED OFFICE (DO/EO/US)  
CONCERNING A FILING UNDER 35 U.S.C. 371

U.S. APPLICATION NO. (if known see 37 C.F.R. 1.5)  
**09/646032**

INTERNATIONAL APPLICATION NO.  
PCT/GB99/00765

INTERNATIONAL FILING DATE  
15 March 1999

PRIORITY DATE CLAIMED  
13 March 1998

TITLE OF INVENTION  
**FIELD EMISSION CATHODE AND FIELD EMISSION DISPLAY**

APPLICANT(S) FOR DO/EO/US  
**William ECCLESTON, Gehan Anil Joseph AMARATUNGA and Ismail MUSA**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

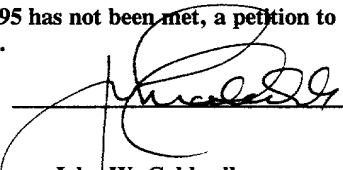
- 1.  This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
- 2.  This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
- 3.  This express request to begin national examination procedures (35 U.S.C. 371(f) ) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
- 4.  A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
- 5.  A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is transmitted herewith (required only if not transmitted by the International Bureau).
  - b.  has been transmitted by the International Bureau.
  - c.  is not required, as the application was filed in the United States Receiving Office (RO/US)
- 6.  A translation of the International Application into English (35 U.S.C. 371(c)(2)).
- 7.  Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
  - a.  are transmitted herewith (required only if not transmitted by the International Bureau).
  - b.  have been transmitted by the International Bureau.
  - c.  have not been made; however, the time limit for making such amendments has NOT expired.
  - d.  have not been made and will not be made.
- 8.  A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
- 9.  An oath or declaration of the inventor(s) 35 U.S.C. 371(c)(4).
- 10.  A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11. to 16. below concern other document(s) or information included:**

- 11.  An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
- 12.  An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
- 13.  A **FIRST** preliminary amendment.  
 A **SECOND** or **SUBSEQUENT** preliminary amendment.
- 14.  A substitute specification.
- 15.  A change of power of attorney and/or address letter.
- 16.  Other items or information:
  - A copy of the **Published PCT** application as published by WIPO under No. **WO 99/48122**, including the Search Report
  - A copy of the **International Preliminary Examination Report**, including Replacement page nos. 4, 7 and claims

EXPRESS MAIL Mailing Label No. **EL531447225US**  
 Date of Deposit: **September 13 2000**  
 I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231  
 MAILER **Robert Galonsky**  
 SIGNATURE Robert Galonsky

RECEIVED  
SEP 13 2000  
PCT/PTO

|  |              |  |            |  |    |
|--|--------------|--|------------|--|----|
| U.S. APPLICATION NO. (if known, 37 C.F.R. 1.5)<br><b>09/646032</b>   |              | INTERNATIONAL APPLICATION NO.<br><b>PCT/GB99/00765</b> |            | ATTORNEY DOCKET NUMBER<br><b>THOM-0012</b>   |    |
| 17. <input checked="" type="checkbox"/> The following fees are submitted:<br><b>Basic National Fee (37 CFR 1.492(a)(1)-(5)):</b><br>Search Report has been prepared by the EPO or JPO.....\$840.00<br><br>International preliminary examination fee paid to USPTO (37 CFR 1.482)<br>.....\$670.00<br>No international preliminary examination fee paid to USPTO (37 CFR 1.482) but<br>international search fee paid to USPTO (37 CFR 1.445(a)(2)).....\$690.00<br><br>Neither international preliminary examination fee (37 CFR 1.482) nor international<br>search fee (37 CFR 1.445(a)(2)) paid to USPTO.....\$970.00<br><br>International preliminary examination fee paid to USPTO (37 CFR 1.482) and all<br>claims satisfied provisions of PCT Article 33(2)-(4).....\$96.00 |              |  |            | CALCULATIONS      PTO USE ONLY   |    |
|  |              |  |            | <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>  |    |
| Surcharge of \$130.00 for furnishing the oath or declaration later than _ 20 _ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).  |              |  |            | \$   |    |
| Claims   | Number Filed | Number Extra   | Rate       |  |    |
| Total claims   | - 20 =       |  | X \$18.00  | \$   |    |
| Independent Claims   | - 3 =        |  | x \$78.00  | \$   |    |
| Multiple dependent claims(s) (if applicable)   |              |  | + \$260.00 | \$   |    |
| <b>TOTAL OF ABOVE CALCULATIONS =</b>   |              |  |            | <b>\$ 840.00</b>   |    |
| Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).   |              |  |            | \$   |    |
| <b>SUBTOTAL =</b>  |              |  |            | <b>\$ 840.00</b>   |    |
| Processing fee of \$130.00 for furnishing the English translation later than the _ 20 _ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).   |              |  |            | +  | \$ |
| <b>TOTAL NATIONAL FEE =</b>  |              |  |            | <b>\$ 840.00</b>   |    |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property   |              |  |            | +  |    |
| <b>TOTAL FEES ENCLOSED =</b>   |              |  |            | <b>\$ 840.00</b>   |    |
|  |              |  |            | <b>Amount to be:</b>   |    |
|  |              |  |            | <b>refunded</b>  | \$ |
|  |              |  |            | <b>charged</b>   | \$ |
| a. <input checked="" type="checkbox"/> A check in the amount of \$ <b>840.00</b> to cover the above fee is enclosed.<br>b. <input type="checkbox"/> Please charge my Deposit Account No. 23-3050 in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.<br>c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 23-3050. A duplicate copy of this sheet is enclosed.   |              |  |            |  |    |
| <b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.</b>   |              |  |            |  |    |
| SEND ALL CORRESPONDENCE TO:<br><b>John W. Caldwell</b><br>Woodcock Washburn Kurtz<br>Mackiewicz & Norris LLP<br>One Liberty Place - 46th Floor<br>Philadelphia, PA 19103<br>(215) 568-3100   |              |  |            | <br>_____<br><b>John W. Caldwell</b><br>NAME |    |
|  |              |  |            | _____<br><b>28,937</b><br>REGISTRATION NUMBER  |    |

U.S. PATENT AND TRADEMARK OFFICE  
 FORM 37 (01-00) PREVIOUS EDITIONS ARE OBSOLETE

WO 99/48122

6/PRTS

09/646032

PCT/GB99/00765

532 Rec'd PCT/PT 13 SEP 2000

- 1 -

DESCRIPTIONFIELD EMISSION CATHODE AND FIELD EMISSION DISPLAY

The present invention is concerned with field emission electrodes and with field emission displays.

A great deal of research effort has been devoted in recent years to developing a display which can replace the conventional cathode ray tube (CRT). Shortcomings of the CRT include its weight and bulk, and also its requirement for relatively high input power. The CRT is also unsuited to use in large area displays eg. in stadia and in small displays for laptops, watches etc.

The liquid crystal display (LCD) provides an alternative which is not subject to some of the disadvantages of the CRT. It can be manufactured in flat panel format, and used both in miniature displays and in larger displays, eg. in wide format television sets. However, LCD displays suffer from disadvantages of their own, particularly with regard to display brightness.

A promising alternative to both LCDs and CRTs is the field emission display (FED). FEDs offer the prospect of flat panel displays which are superior to LCD screens in brightness, colour rendition, response time and operating temperature range.

In known FEDs, electrons are released from a cathode by field emission (rather than by thermionic emission, as in the CRT) and accelerated toward an anode which is maintained at a positive potential typically of several kV. The electrons

WO 99/48122

PCT/GB99/00765

- 2 -

impinge on the phosphor pixels which are thereby caused to luminesce, providing the display. To generate the field needed for release of electrons, a matrix of switchable row and column electrodes is typically provided, in addition to the anode, and in this way pixels can be individually addressed.

A particular problem has been found in providing a cathode which exhibits field emission at electric field strengths which can be provided in a practical display, without the need for unacceptably large power and voltage.

Known FEDs typically utilise cathodes having on their surface an array of microscopic pointed elements known as Spindt tips, formed of Mo or Si. The tips are very sharp - having radii of the order of 20nm - thereby providing large local electric fields to cause field emission. This is necessary because in the materials of such known cathodes the work function (the energy needed to release an electron from the cathode) is otherwise relatively high - of the order of 5eV. These known cathodes are not straightforward to manufacture and suffer from reliability problems due to erosion of the field tips.

An alternative approach which has been proposed is to provide a cathode lacking Spindt tips but formed of material having low (or even negative) electron affinity. Electrons may be released from such a material by relatively small electric fields.

There is in almost all such field emission systems the need to electrically condition the cathode before low threshold emission is possible. Diamond like carbon (DLC) films have given high emission, particularly when doped with

WO 99/48122

PCT/GB99/00765

- 3 -

nitrogen. One such doped material has provided what is believed to be the lowest threshold reported at the priority date. The nature of the bonding is thought to be an important factor with diamond-like  $sp^3$  bonds being appropriate for producing the energy levels associated with a low electron affinity.

Current understanding of the main features of the emission processes is incomplete, but it is believed that the density of  $sp^3$  bonds and the presence of hydrogen are important. An alternative model is based on a dual process which involves electron heating in the DLC conduction band due to its internal electric field and emission over the relatively low surface potential barrier (electron affinity). Nitrogen acts as a donor fostering the formation of a high field depletion region. This high field region promotes transfer of electrons from substrate to film.

Although DLC film cathodes have hitherto been considered the most promising candidate, the results have not been sufficiently impressive for displays based on such materials to be considered an immediate replacement for the CRT and LCD.

A first object of the present invention is to provide an improved field emission cathode.

It is desired that such a cathode should exhibit field emission when subject to an electric field of a magnitude which can be created in a practical display.

It is additionally or alternatively desired that such a cathode should exhibit stable field emission properties.

It is additionally or alternatively desired that such a cathode should be capable

ART 34 AMP

4

of manufacture in suitable form for use in a field emission display.

In accordance with a first aspect of the present invention, there is provided a field emission cathode comprising conjugated polymer material forming a field emission surface.

The inventors have fortuitously (and most unexpectedly) discovered that polymer materials can be manufactured giving high electron emission. Polymer materials can be formed by known techniques into uniform cathodes, which may be large in area, and can be highly stable. Exclusion of oxygen is considered useful for the stability of the material.

Conjugated polymers typically have high density of free electrons. Most polymer films are p type with few free electrons; the substrate of the cathode can itself contribute electrons.

Such materials are known for other applications in electronics, which utilise semiconductor type properties of certain conjugated polymers. The usual applications proposed for conjugated polymers - eg. in light emitting structures, photocopiers, photodetectors and thin film transistors - do not require the material to have a low work function, and it is believed that this property of such materials has not hitherto been utilised. The present inventors have found that some such polymeric materials are capable of producing very high steady state field emission currents with the threshold field needed to initiate field emission being smaller than for any other so far reported.

It is especially preferred that the polymer material is a substituted

WO 99/48122

PCT/GB99/00765

- 5 -

polythiophene, and polyalkylthiophenes are particularly suitable. Poly -3-octylthiophene is currently the preferred material.

The polymer material may take the form of a layer on a substrate. It is especially preferred that the polymer layer is formed as a film with thickness of the order of 5 $\mu$ m.

The polymer material is preferably spun from a liquid source or is evaporated in a vacuum onto a substrate, techniques which can produce a large area cathode. A light and economical cathode can be produced in this way.

It is preferable that the polymer material should have a low barrier to electrons of the substrate on which it is formed.

The polymer material may be doped with an electron donor material. The electron donor may be nitrogen (known to reduce the barrier to electrons of the substrate of diamond-like carbon). In fact, un-doped polymers have relatively low number of electrons but transport electrons from the substrate very efficiently. This leaves a great deal of scope for improvement by doping.

The polymer material may have energy levels which trap electrons serving to concentrate the electric field. In this way, field emission is promoted. In a preferred structure, the polymer material forms a film on a substrate comprising microcrystalline silicon. The grain boundaries at the polysilicon surface trap large numbers of electrons as the surface becomes more n type, and so are able to concentrate the field at these points, promoting increased emission from the polymer film.

WO 99/48122

PCT/GB99/00765

- 6 -

It is believed that in the material samples which led to the inventors' initial discovery, voids observed on the material surface, believed to be due to solvent evaporation, serve to create large local electric fields at certain parts of the field emission surface and to promote field emission.

However, a great advantage of the use of polymer materials is that many of them can be shaped by use of a mould. The term "mould" as used throughout this document must be understood to include any type of process in which the polymer is shaped by contact with an appropriately formed tool which is then removed and "moulding" is to be correspondingly construed. By moulding the polymer's emission surface can be shaped such as to promote field emission, eg. by forming tips thereon.

In accordance with a further aspect of the present invention, there is a field emission display having a cathode in accordance with the first aspect of the invention.

There are however other applications for the cathode.

At the low field strength which is sufficient to cause field emission from the cathode according to the present invention, emitted electrons may be insufficiently energetic to cause luminescence of a display screen. This problem is experienced when a phosphor screen is used.

Hence a preferred form of visual display device according to the present invention comprises a grid positioned with respect to the cathode such as to be capable of causing field emission therefrom, an acceleration anode positioned beyond



ART 34 AMDT

7

the grid and a luminescent screen, wherein electrons are selectively emitted from the cathode under the influence of the grid and then accelerated onto the screen with sufficient energy to cause it to luminesce by the acceleration anode.

In accordance with a third aspect of the present invention, there is a method of fabricating a field emission cathode comprising forming a layer comprising conjugated polymer material on a substrate, the polymer material forming a field emission surface of the cathode.

The polymer material may be any of the polymer materials referred to above with respect to the first aspect of the invention.

Specific embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 is a graph of normalised or average field emission current density (on a logarithmic scale of  $A\text{cm}^{-2}$  on the vertical axis) against applied voltage for a cathode embodying the present invention;

Fig. 2a is a graph of normalised field emission current density from a cathode according to the present invention in  $A\text{cm}^{-2}$  and a logarithmic scale on the vertical axis against normalised applied electric field on the horizontal axis, measured in volts per  $\mu\text{m}$ . Results are shown for three anode-cathode spacings, the left-most line being for a spacing of  $27\mu\text{m}$ , the middle line for  $47\mu\text{m}$  and the right-most line for  $130\mu\text{m}$ ;

Fig. 2b is a graph of normalised field emission current density from a cathode according to the present invention in  $A\text{cm}^{-2}$  and a logarithmic scale on the vertical

WO 99/48122

PCT/GB99/00765

- 8 -

axis against applied anodic voltage on the horizontal axis. Results are shown for the three anode-cathode spacings mentioned above with reference to Fig. 2a;

Fig. 3 is a graph of field emission current from a cathode according to the present invention in  $\mu\text{A}$  on the vertical axis against time in hours on the horizontal axis;

Fig. 4 shows band diagrams for a cathode according to the present invention comprising a P3OT layer on a p-Si substrate when subject to no bias (Fig. 4a) and when subject to a biasing field from an Al anode (Fig. 4b);

Fig. 5 shows band diagrams for a cathode according to the present invention comprising a P3OT layer on a n-Si substrate when subject to no bias (Fig. 5a) and when subject to a biasing field from an Al anode (Fig. 5b);

Fig. 6 is a band diagram representing a model for the field emission of electrons into the vacuum from a cathode according to the present invention;

Fig. 7 represents a simple model of field emission from a cathode according to the invention;

Fig. 8 schematically illustrates energy levels in the region of a void of the surface of a cathode according to the present invention;

Fig. 9 is a graph of predicted field emission current (in a logarithmic scale as the vertical axis) against anodic voltage on the horizontal axis assuming a simple one dimensional model for three different anode/cathode separations;

Fig. 10 illustrates a step in the process of moulding a polymer layer of a cathode according to the present invention, the cathode and mould being seen in cross

WO 99/48122

PCT/GB99/00765

- 9 -

section;

Fig. 11 illustrates in cross section a structure of a display device constructed in accordance with the present invention; and

Fig. 12 illustrates in cross section a further structure of a display device according to the present invention.

A first specific embodiment of the invention comprises a field emission cathode formed as a thick ( $5\mu\text{m}$ ), spin-cast, nominally undoped polymer (regioregular poly-3-octylthiophene - P3OT) which is capable of high, stable electron emission. The observed threshold field ( $0.2\text{MVcm}^{-1}$ ) is the lowest so far reported among carbon based materials.

P3OT can be synthesised in pellets by the technique reported in Chen, T-A, Wu, X-M & Rieke, R.D.: Regiocontrolled synthesis of poly (3-alkylthiophenes) mediated by Rieke inc: their characteristics and solid state properties, J. Am. Chem. Soc. 117,233-244 (1995). However during trials carried out by the inventors the material was purchased from a commercial source.

During trials, chloroform has been used as a solvent: dissolving 5mg of P3OT in 1ml of chloroform resulted in films of thickness  $5\mu\text{m}$ .

In initial tests the solution was cast onto a pre-cleaned 1cm x 1cm highly doped n-Si substrate (resistivity  $0.003\text{-}0.01\Omega\text{ cm}$ ) in a clean non-vacuum atmosphere. The optical Tauc bandgap was determined, at room temperature, to be  $-1.75\text{eV}$  by ultraviolet-visible spectrophotometry (this bandgap is defined as the intercept of the gradient of a  $(\alpha E)^{1/2}$  versus E plot with the E axis where  $\alpha$  is the absorption

WO 99/48122

PCT/GB99/00765

- 10 -

coefficient and  $E$  the photon energy). In addition, a single broad absorption maximum was observed at  $\sim 2.38\text{eV}$ , which suggests that these "as synthesized" films are only slightly doped. Nuclear magnetic resonance measurements indicate a regular "head-tail" arrangement of the alkyl side chains (which can be thought of as a measure of how ordered the polymers are) of  $>90\%$ . Such high regularity has only recently become available. It may not be essential for this application. Following casting the P3OT/ $n^{++}$ -Si devices were immediately placed in a vacuum of pressure  $\sim 10^{-7}$  torr to dry for 24 hours.

No special processes were introduced to eliminate the effects of light or air during preparation of the films. Hence in these initial trials they were invariably p type.

Field-emission experiments have been carried out using cathodes formed in the above manner in the flat plate configuration with an indium tin oxide coated glass anode. The separation between the anode and cathode was varied between  $27\mu\text{m}$  and  $130\mu\text{m}$  using glass-fibre spacers. The pressure in the vacuum was  $\sim 2 \times 10^{-7}$  torr. As with many carbon based materials it was necessary initially to ramp the anode voltage to a high level to achieve field emission - ie. to condition the film. Fig. 1 shows typical current-voltage (I-V) characteristics. Two regions are clearly identified (called here 1 and 2). Regions 1a and 1b represent the emission before conditioning and region 2 is after conditioning. A highly stable and reproducible current level was maintained after conditioning. The conditioning field was always below  $10\text{V}\mu\text{m}^{-1}$  in order to avoid any influence of vacuum breakdown phenomena,

WO 99/48122

PCT/GB99/00765

- 11 -

which can occur at fields above  $15\text{V}\mu\text{m}^{-1}$  at the pressure used.

The results were found to be repeatable with or without the spacer being in contact with the ITO anode. Raising the pressure caused the emission current measured at the anode to fall to zero. The emission current was found to scale with the area of the film rather than its perimeter, indicating that edge effects were not dominant.

The remarkable current density (J)- electric field (F) characteristics, with threshold field of only  $\sim 0.2\text{V}\mu\text{m}^{-1}$  for a current density of  $1\mu\text{A}\text{cm}^{-2}$ , are shown in Fig. 2a. Fig. 2b shows the J-F characteristics as a function of anode-cathode spacing. In addition a slope of 1.8 of the log I-log V plot indicates that a space-charge-limited current (SCLC) may be limiting the emission process. The measured anode voltage versus gap separation is shown in Fig. 2a inset and indicates a nonlinear relationship. This shows that surface and bulk charge properties may be important to the emission process.

The surface morphology of the film was examined by scanning electron microscopy (SEM) both before and after field emission. There was no apparent explosive destruction of the film, which can be associated with discharge current phenomena during field emission. The polymer films show void-like features on the surface, of density  $\sim 4 \times 10^4\text{cm}^{-2}$  and of sizes ranging from  $0.40\mu\text{m}$  to a few micrometres.

The inventors also examined the stability of the emission current over time. The emission characteristic recorded over a 16 hour period of continuous emission

WO 99/48122

PCT/GB99/00765

- 12 -

is shown in Fig. 3. The initial current drops to 55% of its value in 2 hours, and thereafter remains stable. The sensitivity of the emission to a change in pressure was also examined: the emission current dropped to below 10pA when the pressure rose to  $10^{-3}$  torr.

An explanation of the current understanding of the physics of certain exemplary embodiments of the present invention is given below, but it must be understood that the inventors do not thereby intend to limit themselves to any particular model or theory explaining the operation of the present invention.

The band diagram of Fig 4 for an aluminium anode predicts a very rapid rise of current which is observed with positive voltage on the aluminium. Space charge limited current kinks would be expected with a high density of donor-like traps in the bottom half of the P3OT energy gap. Al gives excellent Schottky barriers on p-Si, with high on/off ratios.

The band diagram for the n substrate (Fig. 5) also predicts high forward currents, this time due to electrons. Now there is significant distortion due to the effects of trapped electrons in acceptor-like traps in the top half of the band gap. Only a single trapping level is apparent, although a second one could be the cause of the saturation of the current at about  $10^{-4}$  A. A second interpretation is considered less likely: a low density of states at the edge of the conduction band could, in principle, explain the dominance trapping and hence the presence of such distinct space charge limited effects.

The inventors conclude that the n-Si barrier is a reasonably efficient injector

WO 99/48122

PCT/GB99/00765

- 13 -

of electrons, that the effective lifetime of electrons in the polymer is, for minority carriers, surprisingly large. The density of traps in the top half of the polymer energy gap is significantly higher than in the lower half.

A further condition must be met for efficient field emission: there must be an efficient mechanism for injection of electrons into the vacuum. The electron affinity of polymers is low but positive. There is, therefore, a barrier to electrons at the surface of the polymer. Electrons concentrate at this barrier, and most become trapped in the top half of the energy gap, close to the surface. There will, therefore, be significant curvature of the conduction band, with the Fermi level near to the conduction band edge. This promotes electron emission via tunnelling across the barrier (Fig. 6). Some of the electrons may travel ballistically across the narrow surface space charge region where they encounter a smaller tunnelling distance. Further down the conduction band where the concentration of free electrons is higher the tunnel distance is lower. Fig. 7 shows the proposed model in its simplest form. The electron density falls with distance from the silicon cathode, whilst the field increases to maintain  $nE$  and therefore the current density constant. Standard analysis of space charge limited currents in thin films gives.

$$Jx_f = \frac{(\epsilon \mu e)}{2} (E_1^2 - E_2^2)$$

WO 99/48122

PCT/GB99/00765

- 14 -

where  $x_f$  is the film thickness,  $\Theta$  is the ratio of the free to total electron concentration in the film,  $\mu$  is the free electron mobility,  $\epsilon = \epsilon_0 \epsilon_r$  where  $\epsilon_r$  is the relative permittivity of the polymer and  $\epsilon_0$  is the permittivity of free space.  $E_1$ ,  $E_2$  and  $E_{vac}$  are various field strengths defined in Fig. 5.

The field within the surface of the polymer and the field in the vacuum are related by:

$$\epsilon E_2 = \alpha \epsilon_0 E_{vac}$$

where  $\alpha$  is the field intensification multiplier just outside the polymer surface.

As mentioned above, there is evidence from AFM and SFM pictures that voids exist in the surface of films prepared in the way described above. It is proposed that these voids are the source of the field intensification and that the electron current that flows has two components, one from the space charge limited behaviour described above and a second due to free space charge within the void itself. Such a current would also be space charge limited obeying Child's Law. Both of these forms of space charge limited current have the form  $J \propto V^n$  where  $n=1.5$  in the case of vacuum (Child's Law) and  $n=2$  with solids. The rim of the void is found to have a lip, shown schematically in Fig.8, together with the regions where  $n=1.5$  and  $n=2$ . The lip will act as an effective intensifier of the field.

Because the vacuum gap is much larger than the film thickness the two forms of current must mix in this region and space charge in the vacuum due to Child's Law, in the region above the lips, will regulate the current from the  $n=2$  region. Similarly abrupt changes of potential will not be possible between the lips and the



WO 99/48122

PCT/GB99/00765

- 15 -

adjacent space in the void - which is of the order of  $1\mu\text{m}$  in diameter or less. This will regulate current from the void. These effects are not amenable to 1D analysis, so we make a simplifying assumption that the two current densities are equal, as are, approximately, the two areas of emission. The resulting current voltage plots are shown in Fig. 9 for the three vacuum gaps used in the field emission experiment. Although the plots accurately predict the slope of 1.8 for all three cases, as well as for a range from 10V to 1KV (not shown), there is a discrepancy in the thickness dependence.

Strictly speaking one would expect the simple analysis provided here to only apply for vacuum gaps comparable in size to the thickness of the polymer film. Extension to greater gap size is the subject of 2D modelling.

The inventors have speculated that the voids in the polymer film may be created by solvent evaporation during the manufacturing process. In working displays an alternative method of creating the necessary morphology is considered desirable and to this end the polymer film may be shaped against a mould. In such a process, the polymer material may be cast or centrifugally spun and thereby distributed over the substrate. A female mould, seen at 100 in Fig. 10, is then pressed against the upper surface of the polymer 102. In Fig. 10, the substrate is seen at 104.

Polymers can be well suited to moulding processes.

In the illustrated embodiment, the mould is shaped to form in the polymer a number of emission tips 106.

Display devices embodying the present invention are illustrated in Figs. 11

WO 99/48122

PCT/GB99/00765

- 16 -

and 12.

In the simplified FED device structure illustrated in Fig. 11, the field emission cathode is a flat film 2 of polymer material disposed on a conducting substrate 3 maintained at low electrical potential. An anode 4 is provided in front of the cathode, and bears pixels 5 of a material which emits light when struck by energetic electrons, to produce the display. The anode may consist of a light emitting phosphor on glass. Between the anode and the cathode is a grid 6 which can be selectively positively charged. The space 7 between the anode and the cathode is a vacuum.

In operation, selected regions of the grid 6 are charged positively (relative to the cathode) producing the field necessary for field emission of electrons from corresponding regions of the cathode. These electrons are accelerated through the grid by the electric field due to the anode 4, and strike the anode causing it to emit light in selected regions of the screen.

A more detailed illustration of a suitable device structure is given in Fig. 12. Here the cathode is formed by a shaped polymer layer 52 on a substrate 54 which may be of glass. Spacers 56 separate the cathode from a conducting grid 58, penetrated by apertures 60 through which emitted electrons can reach a screen forming the anode and comprising a luminescent phosphor anode 62 on a glass substrate 64. Here it is the grid 58 which modulates the field emission (being positively charged relative to the cathode to the low voltage needed to produce field emission with the type of cathode described herein). The anode 62 is maintained at



CLAIMS

ART 34 AMDT

1. A field emission cathode comprising conjugated polymer material forming a field emission surface.
2. A field emission cathode as claimed in claim 1 wherein the polymer material is a substituted polythiophene.
3. A field emission cathode as claimed in any preceding claim wherein the polymer material comprises a polyalkylthiophene.
4. A field emission cathode as claimed in any preceding claim wherein the polymer material comprises poly-3-octylthiophene.
5. A field emission cathode as claimed in any preceding claim wherein the polymer material is formed as a layer on a substrate.
6. A field emission cathode as claimed in claim 5, wherein the polymer material layer is formed from a polymer solution which is distributed on the substrate, the solvent being evaporated during manufacture to leave behind the polymer layer.
7. A field emission cathode as claimed in claim 6, wherein the solvent is evaporated under vacuum.
8. A field emission cathode as claimed in claim 6 or claim 7, wherein the surface of the polymer layer comprises voids which are formed by solvent evaporation.
9. A field emission cathode as claimed in any of claims 1 to 7, wherein the surface of the polymer material is shaped by use of a mould.

10. A field emission cathode as claimed in claim 9 wherein the moulded shape of the polymer material surface comprises projections which promote field emission.

11. A field emission cathode as claimed in any preceding claim, wherein the polymer material is doped with an electron donor material.

12. A field emission display comprising a field emission cathode as claimed in any preceding claim.

13. A field emission display device as claimed in claim 12, comprising a first anode separated from the cathode such as to be capable of causing field emission therefrom, a second anode positioned beyond the first anode and a luminescent screen, wherein electrons are selectively emitted from the cathode under the influence of the first anode then accelerated onto the screen with sufficient energy to cause it to luminesce by the second anode.

14. A method of fabricating a field emission cathode comprising forming a layer comprising conjugated polymer material on a substrate, the polymer material forming a field emission surface of the cathode.

15. A method as claimed in claim 14, wherein a polymer solution is distributed on the substrate and the solvent is evaporated to leave behind the polymer layer.

16. A method as claimed in claim 15, wherein the solvent is evaporated under vacuum.

17. A method as claimed in claim 15 or claim 16, comprising the further step of shaping the surface of the polymer material by use of a mould.

11/09 '00 15:51 +44 151 709 0162 W.P.THOMPSON 039











5/6

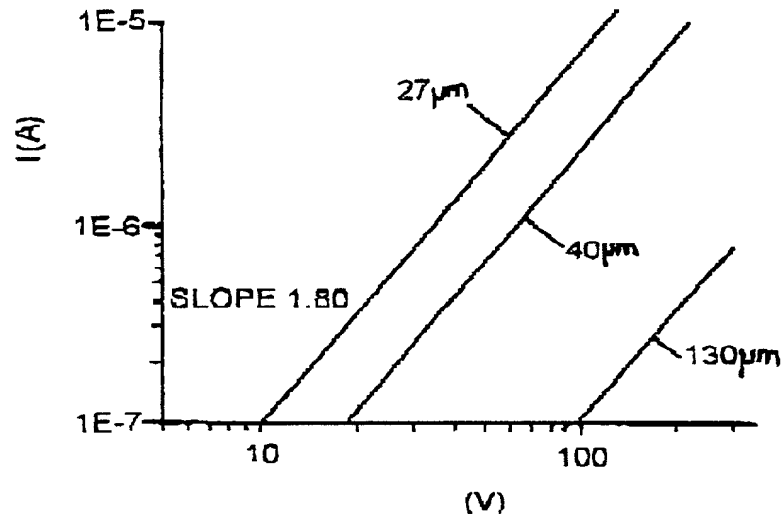


FIG. 9.

FIG. 10.



DocId:32864603

6/6

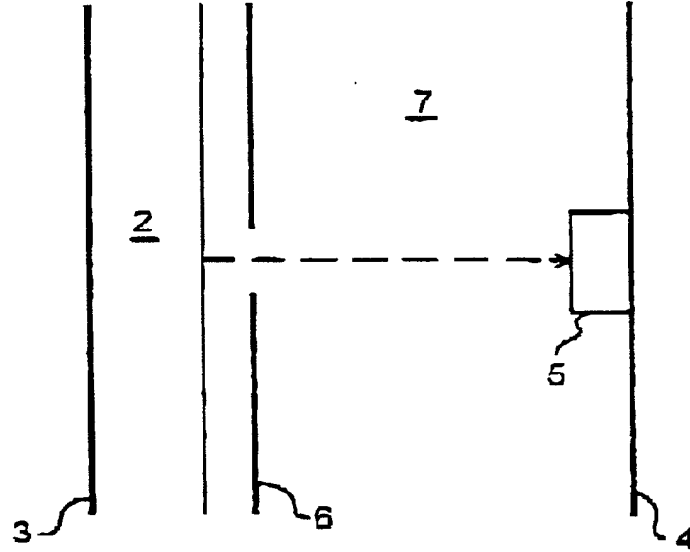


FIG. 11.

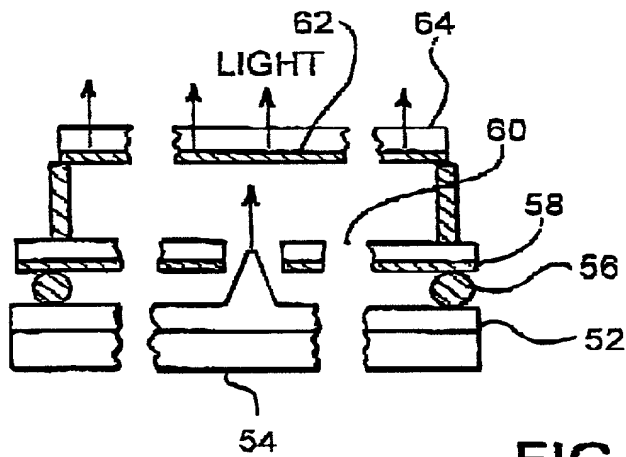


FIG. 12

OFFICE OF THE COMMISSIONER OF PATENTS AND TRADEMARKS



known to be material to the patentability of this application in accordance with 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a-d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of any application on which priority is claimed:

| Priority Claimed (If X'd)           | Country       | Serial Number | Date Filed    |
|-------------------------------------|---------------|---------------|---------------|
| <input checked="" type="checkbox"/> | Great Britain | 9805271.5     | 13 March 1998 |
| <input type="checkbox"/>            |               |               |               |

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose to the U.S. Patent and Trademark Office all information known to be material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

| Serial Number | Date Filed | Patented/Pending/Abandoned |
|---------------|------------|----------------------------|
|               |            |                            |
|               |            |                            |
|               |            |                            |

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

| Serial Number | Date Filed |
|---------------|------------|
|               |            |
|               |            |

I hereby appoint the following persons of the firm of **WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP**, One Liberty Place - 46th Floor, Philadelphia, Pennsylvania 19103 as attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

John W. Caldwell Reg. No. 28,937  
\_\_\_\_\_ Reg. No. \_\_\_\_\_


Address all telephone calls and correspondence to:

John W. Caldwell  
**WOODCOCK WASHBURN KURTZ**  
**MACKIEWICZ & NORRIS LLP**  
One Liberty Place - 46th Floor  
Philadelphia PA 19103  
Telephone No.: (215) 568-3100  
Facsimile No.: (215) 568-3439

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DOCKET INFORMATION

PO

|   |  |
|---|--|
| <b>Name:</b><br><u>William ECCLESTON</u>  |  |
| <b>Mailing Address:</b><br>8 College Avenue<br>Formby<br><u>Liverpool L37 3JL</u><br>Great Britain <i>GBN</i> | <b>Signature</b><br><br><b>Date of Signature:</b> <u>8.10.2000</u>                   |
| <b>City/State of Actual Residence:</b><br>Liverpool, Great Britain  | <b>Citizenship:</b> <u>Great Britain</u>   |







Date: \_\_\_\_\_

Gehan Anil Joseph AMARATUNGA

**STATEMENT BY WITNESS**

I, \_\_\_\_\_, whose full post office address is

\_\_\_\_\_ was

personally present and did see \_\_\_\_\_ execute the above

assignment on the \_\_\_\_\_ day of \_\_\_\_\_, 2000, and such assignor is personally known to me to be the person described in such document.

Date \_\_\_\_\_

Signature of Witness

Date: 10/11/00

[Signature]  
Ismail MUSA

**STATEMENT BY WITNESS**

I, DAVID S. BISSETT, whose full post office address is

5 MILNER PLACE, BILLINGHAM, ESSEX, CMR 0TD, was

personally present and did see ISMAIL MUSA execute the above

assignment on the 10<sup>th</sup> day of NOVEMBER, 2000, and such assignor is personally known to me to be the person described in such document.

Date 10/11/00

[Signature]  
Signature of Witness

\* The above assignment covers application Serial No.

09/646,032 filed on 11, year of 2000.

[Signature] The above insertion made by me this 30<sup>th</sup> day of \_\_\_\_\_, year of 2000.

of WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP

WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP

~~PCT~~ Rec'd 30 NOV 2000

DOCKET NO. THOM-0012

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Application of:

William ECCLESTON, Gethan Anil Joseph  
AMARATUNGA and Ismail MUSA

Group Art Unit: not yet known

Serial No.: 09/646,032

Examiner: not yet assigned

International Application No.: PCT/GB99/00765

International Filing Date: 15 March 1999

For: FIELD EMISSION CATHODE AND  
FIELD EMISSION DISPLAY

Assistant Commissioner for Patents  
Washington DC 20231

Sir:

ASSOCIATE POWER OF ATTORNEY

The undersigned, of the firm WOODCOCK WASHBURN KURTZ  
MACKIEWICZ & NORRIS LLP, One Liberty Place - 46th Floor, Philadelphia, Pennsylvania  
19103, Attorney and/or Agents for Applicant(s), hereby appoints the following:

|                       |                                |                      |                                |
|-----------------------|--------------------------------|----------------------|--------------------------------|
| Robert B. Washburn    | Registration No. <u>16,574</u> | David A. Cherry      | Registration No. <u>35,099</u> |
| Richard E. Kurtz      | Registration No. <u>19,263</u> | Terence P. Strobaugh | Registration No. <u>25,460</u> |
| John J. Mackiewicz    | Registration No. <u>19,709</u> | Lynn A. Malinoski    | Registration No. <u>38,788</u> |
| Norman L. Norris      | Registration No. <u>24,196</u> | Michael J. Swope     | Registration No. <u>38,041</u> |
| Dale M. Heist         | Registration No. <u>28,425</u> | Michael J. Bonella   | Registration No. <u>41,628</u> |
| Gary H. Levin         | Registration No. <u>28,734</u> | Harold H. Fullmer    | Registration No. <u>42,560</u> |
| Steven J. Rocci       | Registration No. <u>30,489</u> | William R. Richter   | Registration No. <u>43,879</u> |
| Dianne B. Elderkin    | Registration No. <u>28,598</u> | John E. McGlynn      | Registration No. <u>42,863</u> |
| John P. Donohue, Jr.  | Registration No. <u>29,916</u> | Jonathan M. Waldman  | Registration No. <u>40,861</u> |
| Henrik D. Parker      | Registration No. <u>31,863</u> | Chad Ziegler         | Registration No. <u>44,273</u> |
| Suzanne E. Miller     | Registration No. <u>32,279</u> | Gwilym J.O. Attwell  | Registration No. <u>45,449</u> |
| Lynn B. Morreale      | Registration No. <u>32,842</u> | David N. Farsiou     | Registration No. <u>44,104</u> |
| Mark DeLuca           | Registration No. <u>33,229</u> | Paul K. Legaard      | Registration No. <u>38,534</u> |
| Joseph Lucci          | Registration No. <u>33,307</u> | Maureen S. Gibbons   | Registration No. <u>44,121</u> |
| Michael P. Dunnam     | Registration No. <u>32,611</u> | Steven H. Meyer      | Registration No. <u>37,189</u> |
| Michael D. Stein      | Registration No. <u>34,734</u> | Paul B. Milcetic     | Registration No. <u>46,261</u> |
| Albert J. Marcellino  | Registration No. <u>34,664</u> | Joseph R. Condo      | Registration No. <u>42,431</u> |
| David R. Bailey       | Registration No. <u>35,057</u> | Michael K. Jones     | Registration No. <u>41,100</u> |
| Doreen Yatko Trujillo | Registration No. <u>35,719</u> | Frank T. Carroll     | Registration No. <u>42,392</u> |
| Barbara L. Mullin     | Registration No. <u>38,250</u> | Mark J. Rosen        | Registration No. <u>39,822</u> |
| Kevin M. Flannery     | Registration No. <u>35,871</u> | Mitchell R. Brustein | Registration No. <u>38,394</u> |
| Michael P. Straher    | Registration No. <u>38,325</u> | Eric H. Vance        | Registration No. <u>47,151</u> |

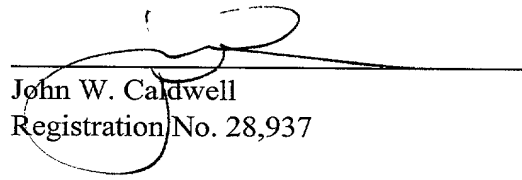
U.S. PATENT AND TRADEMARK OFFICE

60

|                     |                                |                      |                                 |
|---------------------|--------------------------------|----------------------|---------------------------------|
| Peter M. Ullman     | Registration No. <u>43,963</u> | Christine A. Goddard | Registration No. <u>46,731</u>  |
| Thomas E. Watson    | Registration No. <u>43,243</u> | Gregory L. Hillyer   | Registration No. <u>44,154</u>  |
| Richard B. LeBlanc  | Registration No. <u>39,495</u> | Patrick J. Farley    | Registration No. <u>42,524</u>  |
| Joseph D. Rossi     | Registration No. <u>47,039</u> | Ellen M. Klann       | Registration No. <u>44,836</u>  |
| George J. Awad      | Registration No. <u>46,528</u> | Steven B. Samuels    | Registration No. <u>37,711</u>  |
| Steven D. Maslowski | Registration No. <u>46,905</u> | Susan C. Murphy      | Registration No. <u>46,221</u>  |
| S. Maurice Valla    | Registration No. <u>43,966</u> | Roseleen P. Morris   | Registration No. <u>P47,321</u> |
| Vincent J. Rocchia  | Registration No. <u>43,887</u> |                      |                                 |
| Robin S. Quartin    | Registration No. <u>45,028</u> |                      |                                 |

his/her associates with full power to prosecute the above-identified application and to transact all business in the Patent Office connected therewith and requests that correspondence continue to be directed to the firm of WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP at the above address.

Date: *November 30 2000*

  
 John W. Caldwell  
 Registration No. 28,937

Woodcock Washburn Kurtz  
 Mackiewicz & Norris LLP  
 One Liberty Place - 46th Floor  
 Philadelphia PA 19103  
 Telephone: (215) 568-3100  
 Facsimile: (215) 568-3439

WOODCOCK WASHBURN KURTZ MACKIEWICZ & NORRIS LLP